

AN INSIGHT INTO GASIFICATION OF WOODEN STICKS

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ABSTRACT: Wood is considered one of the major biomass. Among the various energy conversion route to convert the wood into useful energy, gasification plays a major role. The properties of wooden sticks influence the temperature distribution within the stick. Gasification is very sensitive to the non-uniformity in temperature. The effect of size and shape, initial porosity, pore distribution, moisture, and ash on wooden sticks' gasification has been discussed. The variations in properties have been attributed to a combined parameter, namely thermal diffusivity (α), and heat transfer dominant in thermal decomposition of wooden sticks. Reviewing of existing investigations leads to the development of a procedure for estimating the weight of wooden sticks yet to be gasified at any time.

Keywords: Initial porosity, Pore distribution, thermal diffusivity, and gasification.

1. Introduction

Applications of wood, ranging from biomass, provide useful energy to building material. Wood consists of components like water, hemicelluloses, cellulose, lignin, and ash. These components are grouped as moisture, volatile matter, fixed carbon, and ash. Except for ash, all other components undergo thermal degradation on heating. Heating uniformly at different temperature ranges releases these components one by one. This results in changes in chemical structure, influence the performance. The degradation depends on the temperature and surface area exposed. Reduced strength and hygroscopic water and volatile oil weight loss result due to these changes.

Since the temperature effects the degradation, the reaching of uniform temperature influences the degree of decomposition. Drying of moisture, devolatilization of volatile matter, and gasification of fixed carbon occur at different temperature levels. If the biomass were powdery and porous, the temperature would be uniform throughout the particle, and each of the above processes will be occurring separately at each temperature level. The reaction takes place continuously at all points.

On the other hand, if the biomass were lumps, then non-uniformity in temperature occurs within the lump. This results in the processes co-occurring. The physical properties of biomass has impact in

influencing the degree of degradation and resulting in biomass's structural characteristics.

Kirubakaran et al. [1,2] have reviewed the gasification of biomass and have concluded that components of carbon, hydrogen, oxygen and ash. On heating, these components decompose to yield various gaseous products and to desorb. Further, they suggested that auto gasification of converting the combustible matter with the inherent oxygen.

However, during the gasification of wooden sticks, the formation of non-uniformity in temperature along the radius cannot be avoided. Several physical properties of wood and end products are responsible for this. The effects of these properties on gasification are reviewed here.

1. Chemistry of Gasification

Wood may be assumed to have cellulose, hemicellulose, and lignin. It may be different for wood due to the presence of inorganic minerals as ash.

Depending upon the exposed temperature and duration, changes in the chemical structure of wood occur, affecting its performance. Reduced strength, hygroscopic water, and volatile oil weight loss result due to these changes. The strength of the wood may be used as a yardstick to measure the degree of degradation of wood due to heating. The water content, medium of heating source, retention time and inherent components affects the decomposition. Permanent

reductions in strength can occur at temperatures below 100°C due to significant carbohydrate weight loss.

Gerhards [3, 4, 5] and Koch [6] have reviewed the reduction in strength due to changes in chemical structure owing to heating wood below 100°C. Chemicals impregnated in wood to reduce its flammability are found to catalyze the degradation of wood at lower temperatures.

Between 100 and 200°C, dehydration of wood gives volatile vapor including vapor and CO₂, formic acid, acetic acid, and H₂O. Char results due to prolonged exposures at higher temperatures. The diffusion of air through the porous char leads to an exothermic reaction.

Compared to Cellulose, the Hemicellulose is less stable and gives volatile gases and less oily vapors. Hardwood hemicellulose is having high xylan and contains less glucomannan, whereas softwood hemicellulose has another way. Xylan is the least thermally stable. Hemicellulose degrades at temperatures from 200 to 260°C.

From 200 to 300°C, hemicellulose is pyrolyzed completely, giving off gases, liquids, and high boiling point tar. Moving on the red bed area tar has been converted into gaseous substances. (Bryden [7]). Deacetylation of hemicellulose yields much of acetic acid, while dehydration of hemicellulose produces char. Char reacts and produces water vapor and carbon dioxide due to raise in the temperature. This makes the reaction as endothermic. During this "low-temperature pathway" of pyrolysis, glowing combustion gets manifested due to exothermic oxygen.

Cellulose unreacted between 200 to 300°C. The conversion of cellulose to combustible gas mixture has been occurred during low temperature only. At higher temperature cellulose has been converted into carboxyl and peroxide groups which are non combustible. This reaction has been occurred in the temperature range of 300 and 350°C.

By the high-temperature pathway, depolymerization takes place yielding glucose. Pyrolysis of lignin takes place between 225 to 450°C. Around 200°C, dehydration of lignin is responsible for pyrolysis, yielding more char. Around 300°C, the

heavier component of lignin has started spooling. Around 370°C to 400°C, the carbon linkage has been cleaved. The decomposition of lignin is an exothermic in nature and the temperature range lies from 225°C and 450°C. The decomposition environment plays a major role in deciding the temperature and its peak.

In wood combustion devolatilization starts around 450°C. The composition of elements present in the wood decides the trends in pyrolysis.

2. Modelling of Thermal Degradation

Several model has been elucidated for the decomposition of wood to recover energy and derived fuels

Di Blasi [8, 9] and Gronli [10] have reviewed the the decomposition of single particles. Also the various authors reported the decomposition rate of wood (Larfelt [11], Larfelt et al. [12], Gronli et al. [13], Janes et al. [14], Di Blasi [15], Larfelt et al. [16], Di Blasi [17], Bryden et al. [18], Hagge et al. [19], Bellais et al. [20], Bryden et al. [21], Babu et al. [22]). Models coupling transport equations for the formation of derived fuels could be implemented to evaluate the performance of gasification processes. The shrinking unreacted-core approximation simplifies these models considerably. Galgano and Di Blasi [23] have presented a unchanged shrinking core model for wood decomposition since the mass transfer plays a major role and a uniform temperature exists in the radial cross section of the wood pyrolysis.

However these models have been validated experimentally for pre-dried fuels. Thus it avoids the influence of moisture. Once moisture is completely removed, it affects the other products formation like char, vapor formation. (Simms et al. [24]) reported that the moisture removal model which can predict ignition time, quality of product gas etc. Moisture content has the major influence of product gas, char formation etc (Gray et al. [25], Chan et al. [26], Di Blasi et al. [27]). Galgano and Di Blasi [28] have modified the unreacted shrinking core model taking into account the effect of moisture. Using 14 parameters taken from literature such as pre-exponential factor, activation energy, thermal conductivities of char and wood, emissivities of

char and wood, etc., they have verified the model satisfactorily for various moisture content and rates of heating.

Furetes and Marbon [29] analyzed the particle physical characteristics on the overall gasification kinetics.

The physical and chemical changes occur in the solid particle during the decomposition. First the solid particle undergoes fragmentation while decomposition starts and finally its strength diminishes and hence makes the particle into finest powdery substances. Modifications in particle size, density variations, surface area, and pore volumes can not be explained by considering the chemical process alone (Smith, [30], Young and Smith [31], Salatino, and Massimilla [32], Kawahata and Walker [33]). Particles are implicitly assumed to react until reaching the porosity one. During the heating the particle gets degraded and converted into fine powder. This will be the phenomenon has been useful in designing fixed and fluidized bed gasifier / combustor.

The size and shape of the particle, initial porosity, pore distribution, ash content, and its composition and moisture have an impact on decomposition of biomass. Their contributions to the rate of gasification are to be evaluated first before attempting any modeling. The following sections describe the process.

3. Effect of Particle size and shape on gasification

The other important phenomenon of the gasification is Particle size. Maa and Bailie [34] have studied the decomposition studies on the various particle size and concluded that both heat transfer and chemical reaction control for lesser particle size, while particle above 6 cm heat transfer controls. Even though spherical particles do not exist in practice, many investigations have been reported due to its simplicity in analyzing the data. Wooden pallets or sticks are very commonly available biomass. Several investigators (Galgano and Di Blasi [28]) have analyzed the course of gasification in detail. Thermal conductivity plays a vital role in deciding the radial temperature profile. Since gasification is a thermal process, non-uniformity

in temperature affects the degree of gasification considerably.

Therefore the bigger the particle size greater would be the thermal gradation which leads all three decomposition stages occurring simultaneously. This results in non-uniform gas composition with varying rates of reaction. The particle property evolves with the extent of reaction. The weight loss represents the sum of the individual losses due to three phases of gasification at a temperature averaged over the entire radius. The temperature increases from the outer radius to the center. Each stage of thermal degradation of biomass takes place whenever the appropriate temperature is reached. For example, around 100°C, drying releases water vapor creating more pores in the biomass. This change in particle property decreases the density and thermal conductivity. However, the product / reacting gases can flow through these pores with the least resistance. This shifts the regime of reaction from internal diffusion control initially to chemical reaction control. If the pore gets widened, then wall strength gets reduced. The wall of pores collapses once a critical thickness is reached.

The porosity corresponding to this thickness is called critical porosity. The onset of peripheral percolation commences at this stage. In the early stages of the reaction, the reaction is taking place at the external surface. Afterward, the shrinkage in particle exclusively to the peripheral percolation. The thermal degradation brings about changes in the particle property. Porosity and pore distribution change considerably, resulting in variation in thermal conductivity and surface area. If the micropores get widened and become macro pores, the porosity increases with a decrease in surface area. Increased pore size reduces the internal diffusion resistances, and the regime of reaction is shifted to chemical control. The increase in porosity reduces the thermal properties. At this stage, the onset of outer peripheral percolation collapses the fragments, and the particle becomes devoid of the porous segments.

Therefore the nature of the influence of particle size on thermal degradation is highly complex. It depends upon the initial porosity, pore distribution,

moisture, and ash. However, for powdery biomass, the temperature is uniform, and the thermal degradation is controlled by chemical reaction alone.

4. Effect of initial porosity

If the initial porosity were low with micropores, then the biomass has a very high surface area and thermal conductivity. The internal diffusion resistance and heat transfer rate would be high. The thermal degradation will be taking place only on the external surface. As the reaction progresses, the porosity increases due to the widening of pores, changing the pores to mesa pores. This reduces the surface area and hence the rate of reaction. The widening of pores reduces the wall thickness. The pore collapses once the porosity becomes critical. This shifts the reaction regime from diffusion resistance to chemical reaction control. The reaction is attributed exclusively to the peripheral percolation

If the initial porosity were low with mesa pores, then the biomass has a low surface area and thermal conductivity. The internal diffusion resistance and the heat transfer rate would be low. The reactant gases diffuse throughout the particle easily. However, non-uniformity in temperature due to poor thermal conductivity is responsible for slowing down the reaction rate. Initially, the reaction is taking place on the external surface, widening the pores further. The particle size shrinks, reducing the internal diffusion resistance further. Therefore with low porosity and mesa pore particle, chemical reaction controls for a considerable amount of time.

If the initial porosity were high with micropores, then surface area, thermal conductivity, and strength parameter would be the highest. The internal diffusion resistance would be controlling. The higher heat transfer rates due to high thermal conductivity reduce the radial temperature variations considerably. The overall rate of thermal degradation would always be high. The strength parameter decreases with the widening of pores, and peripheral percolation commences as discussed earlier. Even though the reaction occurs initially on the external

surface, the peripheral percolation controls the reaction further.

If the initial porosity were high with mesa pore, the surface area, thermal conductivity, and internal diffusion resistance would be the least. The chemical reaction is always controlling. With pore widening due to drying and devolatilization, the strength of the walls becomes reduced. Upon the onset of percolation, the wall collapses, and the particle shrinkage is due to the peripheral percolation. Even though the gases diffuse uniformly, the reaction rate and mechanism are varying radially due to non-uniformity in temperature.

5. Effect of Ash

The ash content and its composition in biomass play a vital role in retaining the shape and catalyzing it. Mineral content in ash has been found to influence the rate of gasification (Raveendran et al. [35]). The strength parameter of the biomass depends the content of inorganic components. The higher the ash more would be the strength and onset of percolation will not influence the reaction. The reaction will be taking place on particle surface. The size and shape of particle do not get altered. On the other hand, with low ash, the particle shrinking is due to peripheral percolation. As discussed earlier, the onset of percolation plays a key role in the progress of reaction due to the particle's low strength parameter. At higher temperatures, ash fuses, they were sealing off the reactants from further reacting.

6. Effect of Moisture

Depending upon the moisture content, the generation of pores or widening of pores occurs at drying temperature. This increases the porosity and reduces the surface area and internal diffusion resistance. Further, the water vapor at high temperatures takes part in the gasification of char.

7. Effect of External Mass Transfer Resistance

External mass transfer resistance hardly affects the conversion, irrespective of the internal diffusion resistance. The evolution of the particle's overall

properties does not get alerted with the extent of external mass transfer resistance. This is exclusively attributed to the heat transfer since the reaction is a thermal process.

8. Effect of Order of Reaction

The onset of percolation influences the order of the reaction. Before the onset of percolation, the diffusion resistance controls the gas concentration within the pores; the reaction order becomes zero, independent of concentration. After the onset of percolation, the reaction depends upon the concentration and order varies between 1/3 to 1.0. Change in order is due to the textural evolution of the properties.

9. Effect of Thermal Diffusivity (α)

It is evident from the above discussion that the variations in initial porosity, pore distribution, ash content, and its composition and moisture influence the thermal degradation of biomass combinedly and make the process very complex. In a wooden stick or lumps, these properties have a pronounced effect on the temperature distribution. Temperature distribution decides the course of the reaction. Temperature distribution depends upon thermal conductivity (k), specific heat (C_p), and density (ρ). All these are not constant and are changing with conversion. Therefore the variations with conversions should be understood first.

Thermal conductivity (k) for nonmetals increases with temperature. (Bird et al. [36]). Powdery substances build in the pores play major role where as crystalline substances molecular interaction is a important component.

For porous solids where radiation between particles becomes an important part of total heat flow, the variations do not follow linear law. (McCabe et al. [36])

Thermal conductivity (k) at room temperature for a considerable variety of wooden biomass may be accurately predicted from

$$k = \rho (0.1159 + 0.00233 M) + 0.01375 \quad (1)$$

where thermal conductivity (k) in B.t.u / hr ft $^{\circ}$ F, density (ρ) in gm /cc and the average moisture content (M) is in weight percent (Perry et al. [38]).

For $M > 40\%$,

$$k = \rho (0.1159 + 0.00316 M) + 0.01375 \quad (2)$$

Specific heat also increases with temperature in the similar way as thermal conductivity (k). Density (ρ) decreases marginally with temperature due to expansion of solid.

Thermal conductivity (k), specific heat (C_p), and density (ρ) are related by a quantity thermal diffusivity (α) (Bird et al. [36]).

$$\alpha = k / (\rho C_p) \quad (3)$$

Therefore thermal diffusivity (α) is independent of temperature for small temperature ranges.

The thermal diffusivities are generally calculated from thermal conductivity (k), specific heat (C_p), and density (ρ) using Equation (3)

It would be better if thermal diffusivity (α) is determined using the same operating conditions for calculating conversion. Further thermal diffusivity (α) is influenced by method of heating. In actual gasifiers, there are different zones of varying temperatures. Wood, while moving from zone to zone, undergoes isothermal and non-isothermal heating during its journey to complete gasification. Under an isothermal heating source, the wood's exterior surface is exposed to the highest temperature, and as time progresses, temperature increases radially. In non-isothermal heating source, the temperature of wood increases gradually in radial direction. Depending upon the method of heating, the radial temperature profile varies resulting in different evolution of particle properties and conversion. Therefore thermal diffusivity (α) should be evaluated along with conversion.

Because of the non-uniform temperature distribution along the radius, drying devolatilization and gasification of wood simultaneously yields different weight losses at different radial positions. However, only the overall weight loss is estimated. Therefore the weight loss should be taken as that had occurred at an average temperature (\bar{T}) prevailing at

that time. Therefore determination of average temperature is crucial.

Average temperatures (\bar{T}) at different time intervals are to be determined. Since thermal diffusivity (α) varies with average temperature (\bar{T}), it is possible to relate them using Fourier's law as follows:[37]

$$\frac{T_s - \bar{T}}{T_s - T_a} = 0.692 e^{-5.78N_{FO}} \quad (4)$$

where,

$$N_{FO} = \alpha t / r_m^2 \quad (5)$$

where,

α = Thermal diffusivity, mm² / minute

t = time, minute and

r_m = mean radius, mm

The effect of isothermal or non-isothermal heating on thermal diffusivity (α) at various times can be established for a given type of biomass. From the relationship thus established, thermal diffusivity (α) can be determined for any heating method at any time. The Fourier number (N_{FO}) can be determined at that time using Equation (5) and the corresponding average temperatures (\bar{T}) from Equation (1). Thus average temperatures (\bar{T}) at various times can be determined. The weight fraction yet to be converted (w) at any time can be obtained experimentally. And the corresponding average temperatures (\bar{T}) can be determined from thermal diffusivity (α). From weight fraction yet to be converted (w) versus time data, the rate (-rd) and rate constant (k) can be related. Using average temperatures (\bar{T}) and rate constant (k), the weight fraction yet to be converted of the wooden stick can be determined at any time.

10. Conclusion

In powdery and porous biomass, the thermal degradation occurs uniformly throughout the particle, and a continuous chemical reaction model can be applied. The thermal degradation of this kind is named auto gasification, wherein heat converts the

combustible solid matter in the biomass in to vapor with the inherent oxygen and catalytic ash.

However, thermal degradation of wooden sticks is influenced by physical properties such as initial porosity, pore distribution, moisture, and ash content. The effect of these properties on conversion has been discussed in detail. The combined effect of these properties can be attributed to a single parameter, namely thermal diffusivity (α). A procedure to evaluate this parameter has been proposed. Following the process outlined, it is possible to determine the weight loss of a wooden stick at any time under a given method of heating.

Nomenclature

k	-	Thermal conductivity
ρ	-	density
M	-	Moisture content
Cp	-	Specific heat
α	-	Thermal diffusivity
\bar{T}	-	Average temperature
t	-	time
r_m	-	Mean radius

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References

- [1.] Kirubakaran V., Sivaramakrishnan V., Nalini R., Sekar T., Premalatha M. and Subramanian P., A review on gasification of biomass. Renewable and sustainable energy reviews 2007 ; 13 (1), 179-186
- [2.] Kirubakaran V., Sivaramakrishnan V., Nalini R., Sekar T., Premalatha M. and Subramanian P., Studies on Auto-gasification of bioresidues. International journal on Energy Resources – Part A 2007, 31, 967-973
- [3.] Gerhards C. C., Effect of high-temperature drying on tensile strength of Douglas-fir 2x4's. For. Prod. J. 1979 ; 29(3) ; 39-46.
- [4.] Gerhards C. C., Effect of moisture content and temperature on the mechanical properties of wood: an analysis of immediate effects. Wood Fiber 1982 ; 14 (1) ; 4-36.

- [5.] Gerhards C. C., Effect of high-temperature drying on the bending strength of yellow-poplar 2x4's. *For. Prod.J.* 1983 ; 33 (2) ; 61-7.
- [6.] Koch P., Drying southern pine at high temperature - a summary of research at Pineville ; 1985.
- [7.] Bryden K. M., Computational modeling of wood combustion. Ph.D. thesis, University of Wisconsin- Madison; WI ; 1998.
- [8.] Di Blasi C., Modeling and simulation of combustion processes of charring and non-charring solid fuels, *Prog. Energy Combust. Sci.* 1993 ; 19 ; 71-104.
- [9.] Di Blasi C., The state of the art of transport models for charring solid degradation, *Polym. Int.* 2000 ; 49 ; 1133-46.
- [10.] Gronli M. G., Ph. D. thesis, NTNU, Trondheim 1996.
- [11.] Larfeldt J., PhD thesis, Chalmers Tekniska Hogskola, Goteborg ; 2000
- [12.] Larfeldt J., Leckner B., Melaaen M. C., Modelling and measurements of the pyrolysis of large wood particles, *Fuel* 2000 ; 70 ; 1637-43 ; 2001.
- [13.] Gronli M. G. and Melaaen M. C., Mathematical model for wood pyrolysis –comparison of experimental measurements with model predictions, *Energy Fuels* 2000 ; 14 ; 791-800.
- [14.] Janse A. M. C., Westerhout R. W. J. and Prins W., Modelling of flash pyrolysis of a single wood particle, *Chem. Eng. Proc.* 2000 ; 39 ; 239-52.
- [15.] Di Blasi C., Kinetic and Heat Transfer Control in the Slow and Flash Pyrolysis of Solids, *Chem. Eng. Sci.* 2000 ; 55 ; 5999-6013.
- [16.] Larfeldt J., Leckner B. and Melaaen M. C., Progress in Thermochemical Bio-mass Conversion, Bridgwater A. V.(Ed.) ; Oxford , Blackwell Science ; 1046-60 ; 2001.
- [17.] Di Blasi C., Modeling wood gasification in a countercurrent fixed-bed reactor, *AIChE J.* 2002 ; 48 ; 2386-97.
- [18.] Bryden K. M., Ragland K.W. and Rutland C.J., Modeling thermally thick pyrolysis of wood, *Biomass Bio-energy* 2002 ; 22 ; 41-53.
- [19.] Hagge M.J., Bryden K.M., Modeling the impact of shrinkage on the pyrolysis of dry biomass, *Chem. Eng. Sci.* 2002 ; 57 ; 2811-23.
- [20.] Bellais M., Davidsson K.O., Lilliendahl T., Sjoström K. and Petterson J.B.C., Influence of mass transfer on thermogravimetric analysis of combustion and gasification reactivity of coke, *Fuel* 2003; 82 ; 1541-8.
- [21.] Bryden K. M. and Hagge M. J., Modeling the combined impact of moisture and char shrinkage on the pyrolysis of a biomass particle, *Fuel* 2003 ; 82 ; 1633-44.
- [22.] Babu B.V. and Chaurasia A.S., Heat transfer and kinetics in the pyrolysis of shrinking biomass particle, *Chem. Eng. Sci.*, 2004, 59, 1999 – 2012.
- [23.] Galgno A., Di Blasi C., *Ind. Eng. Chem. Res.* 2003 ; 42 ; 2101-11.
- [24.] Simms D. L. and Law M., The ignition of wet and dry wood by radiation, *Combust. Flame* 1967 ; 11 ; 377-88.
- [25.] Gray M. R., Corcoran W. H. and Gavalas G. R., Pyrolysis of a wood-derived material. Effects of moisture and ash content, *Ind. Eng. Chem. Res.* 1985 ; 24 646-51
- [26.] Carmen Branca, Colomba Di Blasi, and, Rosario Elefante., *Devolatilization of Conventional Pyrolysis Oils Generated from Biomass and Cellulose Energy & Fuels* 2006, 20 (5) , 2253-2261
- [27.] Di Blasi C., Gonzalez Hernandez E. and Santoro A., Radiative pyrolysis of single moist wood particles, *Ind. Eng. Chem. Res.* 2000 ; 39 ; 873-82.
- [28.] Galgno A., Di Blasi C., Modeling the propagation of drying and decomposition fronts in wood. *Combustion and flame* 2004; 139 ; 16-27
- [29.] Furetes A. B. and Marbon G., Modelling gasification reactions including the percolation phenomenon. *Chem. Eng. Sci.* 1994 ; 49, 3813-21.
- [30.] Smith I. W., The kinetics combustion of pulverized semi-anthracite in the temperature range 1400-2200K. *Combustion Flame* 1971 ; 17 ; 421-8.
- [31.] Young B. C. and Smith I. W., The combustion of Loy Yang brown coal char. *Combustion Flame* 1989 ; 76; 29-35.
- [32.] Salatino P. and Massimilla L., A predictive model for carbon attrition in fluidized bed combustion and gasification of graphite. *Chem. Eng. Sci.* 1989 ; 44 ; 1091-9.
- [33.] Kawahata M. and Walker P. L., Model of porosity development in activated anthracities, *Proceedings of the 5th Carbon conference* 1963, Pergamon press, Oxford, **II** ; 251-63.
- [34.] Maa P. S. and Bailie R. C., Influence of particle sizes and environmental conditions on high temperatures pyrolysis of cellulose material. *Combustion Science Technology* 1973 ; 7 ; 257-69.
- [35.] Raveendran K., Ganesh A. and Khilar K.C., Influence of mineral matter on biomass pyrolysis characteristics. *Fuel* 1995; 74 (12) ; 1812-22.
- [36.] Bird R. B., Stewart W. E., Lightfoot E. N., *Transport Phenomena*. New York, John Wiley & Sons. Inc. ; a) 262 , b) 246 ; 1960.

- [37.] McCabe W. L., Smith J. C. , and Harriott P., Unit Operations of Chemical Engineering. New York ; Mc Graw-Hill Company ; a) 291, b) 301, 1963.
- [38.] Perry R. H., Chitton C. H., and Kirkpatrick S. D., Chemical Engineers Hand book. New York ; Mc. Graw-Hill book company ; 3.224 ; 1963
- [39.] Manikandan, R and Dr.R.Latha (2017). "A literature survey of existing map matching algorithm for navigation technology. International journal of engineering sciences & research technology", 6(9), 326-331.Retrieved September 15, 2017.
- [40.] A.M. Barani, R.Latha, R.Manikandan, "Implementation of Artificial Fish Swarm Optimization for Cardiovascular Heart Disease" International Journal of Recent Technology and Engineering (IJRTE), Vol. 08, No. 4S5, 134-136, 2019.
- [41.] Manikandan, R., Latha, R., & Ambethraj, C. (1). An Analysis of Map Matching Algorithm for Recent Intelligent Transport System. Asian Journal of Applied Sciences, 5(1). Retrieved from <https://www.ajouronline.com/index.php/AJAS/article/view/4642>
- [42.] R. Sathish, R. Manikandan, S. Silvia Priscila, B. V. Sara and R. Mahaveerakannan, "A Report on the Impact of Information Technology and Social Media on Covid-19," 2020 3rd International Conference on Intelligent Sustainable Systems (ICISS), Thoothukudi, India, 2020, pp. 224-230, doi: 10.1109/ICISS49785.2020.9316046.
- [43.] Manikandan, R and Dr.R.Latha (2018). "Map Matching Algorithm Based on a Hidden Markov Model for Vehicle Navigation" International Journal of Advanced Technology in Engineering and Science, 6(6), 36-42.
- [44.] Manikandan, R and Dr.R.Latha (2018). "GLOBAL POSITIONING SYSTEM FOR VEHICLE NAVIGATION" International Journal of Advances in Arts, Sciences and Engineering (IJOAASE), 6(13), 1-9.